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THE GASTROPOD COMMUNITIES IN THE LOWLAND RIVERS OF AGRICULTURAL AREAS - THEIR BIODIVERSITY AND BIOINDICATIVE VALUE IN THE CIECHANOWSKA UPLAND, CENTRAL POLAND

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ABSTRACT

Lowland river degradation of agricultural areas is a problem not only in Poland but also in Europe and worldwide. The objectives of the present study were to determine the biodiversity of the gastropod communities in lowland rivers under the impact of agriculture, the relationship between gastropod communities and environmental factors, and to estimate the usefulness of the gastropod communities as an indicator of water quality. Four rivers that flow through an agricultural area were investigated. A high value of chlorophyll *a*, a low value of total dissolved oxygen and a high concentration of phosphates or total phosphorus and organic matters are present in the rivers. Gastropod communities in the rivers of the Ciechanowska Upland are influenced by bottom sediments, the physical and chemical parameters of water, and the abundance of macrophytes, which are typical of eutrophic water. In the rivers of the Ciechanowska Upland, gastropods can be biological indicators of dissolved oxygen in water – *Viviparus viviparus* (Linnaeus, 1758) and *Lymnaea peregra* (O. F. Müller, 1774) can be indicators of anthropopressure. The values of diversity indices varied from site to site, but did not decrease along the river.

Key words: gastropod communities, lowland rivers, biodiversity indices, agricultural areas, biological indicators, bottom sediments, *Viviparus viviparus* (Linnaeus, 1758), *Lymnaea peregra* (O. F. Müller, 1774).

INTRODUCTION

The cleanness of rivers reflects all human activities within a catchment (Hildrew, 1996). In the rivers of agricultural areas, high concentrations of phosphates or nitrates accelerate the development of phytoplankton, diminishing macrophytes and increasing deficits in dissolved oxygen (Thiébaut & Muller, 1999). It has been estimated that in inland waters, 70% of the total phosphorus comes from surface flow from agricultural areas, 24% comes from municipal sewage, and 19% from detergents (Parr & Mason, 2003). Most rivers in agricultural areas have high concentration of total phosphorus, phosphates, nitrates, suspended solids, and pesticides. This includes such rivers as the Łydynia River, the Pełta River, the Sona River, and the Wkra River, which flow throughout the Ciechanowska Upland in central Poland. Lowland river degradation of agricultural areas is a problem not only in Poland but also in Europe (Solimini et al., 2000; Parr & Masson, 2003) and worldwide (Collier et al., 1998; Harding et al., 1999; Shieh et al., 1999).

Biodiversity assessments are frequently used to monitor the level of pollution (Sandin & Jochnson, 2000; Beaven et al., 2001). Diversity indices such as the Shannon-Wiener index and the Evenness index are based on the following assumptions: (1) there are fewer species in aquatic ecosystems under human impact compared to unpolluted water; (2) the diversity decreases with environmental degradation; and (3) values of the Shannon-Wiener index decrease with increasing pollution (Barton & Metcalfe-Smith, 1992). The objective of the present study were to determine the biodiversity of the gastropod communities in lowland rivers under the impact of agriculture, the relationship between gastropod communities and environmental factors, and to estimate the usefulness of gastropod communities as indicators of water quality.

MATERIALS AND METHODS

Study Area

The study area comprised 2,570 km^2 (the Ciechanowska Upland). The study was carried out in the years 1997–2000. Four rivers of the Ciechanowska Upland: the Łydynia River, the Pełta River, the Sona River and the Wkra River, which flow through this agricultural area, were investgated. Samples were gathered from the overall length of the rivers, but in the case of the Wkra River, only the middle and lower course were sampled (103 km) (Fig. 1). Ten sampling sites were chosen for the Łydynia, Sona, Wkra, and eight for the Pełta River.

The characteristic morphometric features of the rivers are shown in Table 1.

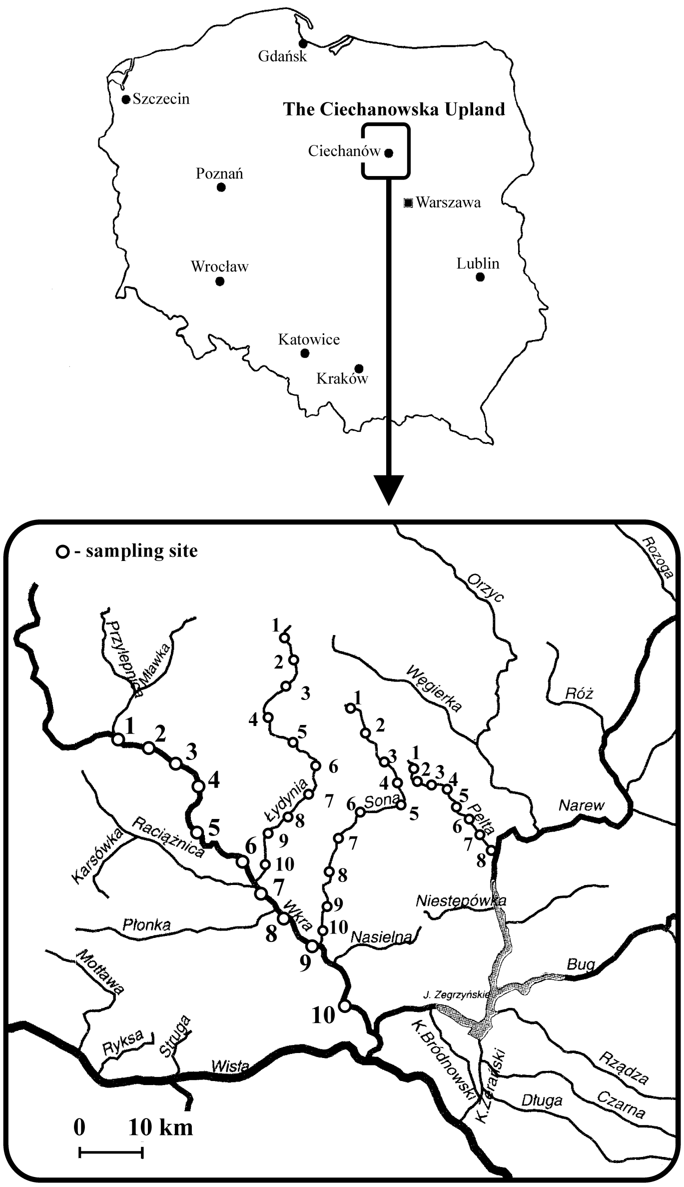

FIG. 1. Location of the study area (the Ciechanowska Upland).

TABLE 1. The morphometry of the rivers and the substratum.

River	Catchment area (in km^2)	River length (in km)	River width (in m)	Surface velocity (ranges) (m/s)	Substratum
Łydynia River	697.9	71.3	1.5–12.0	0.17–0.91	sandy-stony, sandy, stony, stony-sandy
Pełta River	368.7	50.7	0.7–4.0	0.03–0.3	sandy-muddy, sandy-stony, muddy-clay
Sona River	536.5	67.7	0.5–15.0	0.10–0.98	stony, stony-sandy
Wkra River	5,322.1	255.5	10.6–30.5	0.18–0.91	muddy-stony, sandy-muddy, sandy-stony

Methods

Gastropods were sampled by placing a quadrat frame (25 x 25 cm) on the substratum of the river. The frame was placed 16 times at each of the sample stations, which constituted one sample. At each sample station, samples were also taken of bottom sediments up to 5 cm, macrophytes and water surfaces. Only living specimens of gastropds were collected. Bottom sediments were taken by a core-type sampler. The collected material was brought back to the laboratory in plastic bags. The samples were than filtered using a 0.5 mm mesh sieve. The samples of gastropods were preserved in 75% ethanol. The species of most gastropods were identified according to Glöer & Meier-Brook (1998), whereas the Lymnaeidae were identified according to Jackiewicz (1998). The density of gastropods was estimated as the number of individuals per square metre. Immediately prior to gastropod sampling, water samples were collected from each sampling site. The analyses of the physical and chemical parameters of water, for example, temperature, pH, conductivity, dissolved oxygen, BOD_5, sulphates, chlorides, total dissolved solids, alkalinity, calcium, magnesium, ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, phosphates, total phosphorus, and chlorphyll *a*, were carried out according to Hermanowicz et al. (1976). Macrophyte species were recorded on the same visit as gastropod sampling. If macrophyte species could not be identified to species in the field, they were taken to the laboratory, dried between sheets of filter paper and after drying, mounted as ordinary herbarium species. Macrophytes were identified to species according to Szafer et al. (1986). The mineralogical analyses of the bottom sediments were carried out by means of a Siemens D 5,000 powder diffractometer. The organic matter content in the bottom sediments was determined according to Tiurin methods (Lityński et al., 1976). All samples were collected from the head to the mouth of rivers three times at each sample site. In total, 114 sites were sampled within the survey area. The zoocenological study of the gastropod communities was carried out using the following indices:

(1) Dominance (D%)

$D = n_a / n \times 100$

where n_a = the number of individuals of species a,

n = the total number of individuals in a sample.

The value of the dominance index D was divided into five classes according to Górny & Grüm (1981): eudominants > 10.0% of the sample, dominants 5.1–10.0% of the sample, subdominants 2.1–5.05 of the sample, recedents 1.0–2.1% of the sample, subrecedents < 1.0% of the sample.

(2) Constancy (C %)

$C = N_a / N \times 100$

where N_a = number of samples that contain species a,

N = total number of samples.

The value of the constancy index C was divided into four classes: euconstants 75.1–100.0% of the sample, constants 50.1–75.0% of the sample, accessory species 25.1–50.0% of the sample, and accedents ≤ 25.0% of the sample.

Biodiversity indices (Cao et al., 1996; Mouillot & Lepretre, 1999):

(1) The Shannon-Wiener index:

$H' = - \sum (P_i) (\log_2 P_i)$

where $P_i = N_i / N$ – the proportion of individuals belonging to species i.

(2) The Evenness index:
$J' = H' / \log_2 S$
where H' = the value of the Shannon-Wiener index,
S = the total number of species.

Correlation between gastropod density, number of species, organic matter content in the substratum, and the physical and chemical parameters of water were calculated by means of the non-parametric Spearman's Rank Correlation Coefficient r_s. Gastropod frequency in particular rivers in relation to the substratum was calculated by a chi-squared association test (χ^2) (Fovler et al., 1998).

Principal Component Analysis

The studied data sets contain measurement values of 18 various biological, physical and chemical parameters of water, collected at the sampling sites along the Pełta, Łydynia, Sona and Wkra rivers. The water parameters studied are listed in Table 2. The data are organized in matrices X (35 x 18). Each row of matrix X represents one sampling site, described by 18 parameters. Because the measured parameters significantly differ in their ranges, the data set was standardized according to the formula:

$$x_{ij} = \frac{(x_{ij} - \bar{x}_j)}{s_j}$$

where $\bar{x}_j, s_j$ denote the mean of the j-th column and its standard deviation, respectively. Depending on the organization of the data sets, different methods of exploratory analysis can be used. One of the most popular techniques of exploratory analysis of multivariate data sets is principal component analysis (PCA) (Wold, 1987; Massart et al., 1997). This technique allows reduction of data dimensionality, visualization and interpretation of the objects and variables relationships.

RESULTS

Physical and Chemical Parameters of Water and Macrophytes

The physical and chemical parameters of water and macrophyte species are shown in Tables 2 and 3.

A high value of chlorophyll *a*, a low value of total dissolved oxygen, and a high concentration of phosphates or total phosphorus and

TABLE 2. The physical and chemical parameters of water, organic matter content in the substratum, and their values.

Parameters	Łydynia River	Pełta River	Sona River	Wkra River
Temperature (°C)	18.2–20.0	14.8–20.0	15.1–19.5	17.5–19.1
pH	7.7–8.2	7.6–7.9	7.6–8.4	8.0–8.5
Conductivity (µS/cm)	490.0–610.0	691.0–771.0	390.0–681.0	450.0–620.0
Dissolved oxygen (mg O_2/dm^3)	1.60–8.80	6.30–14.10	4.6–10.4	4.50–8.60
BOD_5 (mg O_2/dm^3)	1.80–9.20	1.30–7.80	1.20–5.60	1.20–8.0
Sulphates (mg SO_4/dm^3)	60.0–71.0	42.0–80.0	34.0–79.0	27.0–65.5
Chlorides (mg Cl/dm^3)	23.0–29.0	20.0–51.0	15.0–23.0	19.0–22.0
Total dissolved solids (mg/dm^3)	320.0–372.0	438.0–613.0	280.0–488.0	295.0–369.0
Alkalinity (mg $CaCO_3$/dm^3)	200.0–245.0	290.0–370.0	165.0–210.0	195.0–285.0
Calcium (mg Ca/dm^3)	91.80–100.20	90.70–104.70	64.90–104.0	77.0–101.1
Magnesium (mg Mg/dm^3)	9.70–12.30	16.0–29.50	11.0–18.80	8.30–28.1
Ammonia nitrogen (mg N/dm^3)	0.30–3.74	0.86–1.98	0.06–1.16	0.27–0.92
Nitrite nitrogen (mg N/dm^3)	0.003–0.024	0.008–0.023	0.001–0.060	0.008–0.095
Nitrate nitrogen (mg N/dm^3)	0.07–2.11	0.25–0.60	0.05–0.99	0.06–1.40
Phosphates (mg PO_4/dm^3)	0.40–2.10	0.34–3.71	0.30–0.60	0.68–1.31
Total phosphorus (mg P/dm^3)	0.43–1.01	0.25–1.28	0.18–0.34	0.46–0.60
Chlorophyll *a*(µg/dm^3)	1.80–20.10	3.90–55.1	7.40–81.50	3.8–75.6
Organic matter (%)	1.17–11.86	1.72–28.44	0.43–16.43	0.86–11.10

TABLE 3. Macrophyte occurrence in the rivers of the Ciechanowska Upland.

Species	Łydynia River	Pełta River	Sona River	Wkra River
Acorus calamus L.			+	+
Alisma plantago-aquatica L.			+	+
Berula erecta (Huds.) Coville		+		
Butomus umbellatus L.	+	+		+
Ceratophyllum demersum L. s.s.				+
Elodea canadensis Michx.	+	+	+	+
Equisetum palustre L.				+
Glyceria maxima (Hartm.) Holmb.		+	+	+
Lemna minor L.	+	+	+	+
Lemna trisulca L.	+	+	+	+
Mentha aqatica L.			+	
Myosotis palustris (L.) L. em. Rchb.		+	+	+
Phragmites australis (Cav.) Trin. ex Steud.				+
Nuphar lutea (L.) Sibth. & Sm.	+	+	+	+
Potamogeton crispus L.	+			
Potamogeton natans L.		+		+
Potamogeton pectinatus L.				+
Potamogeton perfoliatus L.	+			
Rumex hydrolapathum Huds.				+
Sagittaria sagittifolia L.		+	+	+
Schoenoplectus lacustris (L.) Palla				+
Sparganium emersum Rehmann				+
Sparganium erectum L. em. Rchb. s.s.	+	+	+	+
Spirodela polyrhiza (L.) Schleid.			+	
Typha latifolia L.				+
Σ of species	8	11	12	20

organic matters were present in the rivers. The main sources of pollution were public utilities, agriculture and the food industry.

The organic matter in the bottom sediments ranged from 0.43% in the Sona River to 28.44% in the Pełta River (Table 2).

Zoocenological Study of the Gastropod Communities

In the rivers of the Ciechanowska Upland, 27 gastropod species were found (Table 4). In the Wkra River, the number of gastropod species was lower than in its tributaries, for example, the Łydynia River and the Sona River. The highest number of gastropod species were found in the Łydynia River. *Valvata piscinalis* (O. F. Müller, 1774) was eudominant in the communities in the Łydynia River and in the Pełta River; *Bithynia tentaculata* (Linnaeus, 1758) was eudominant in the Sona River, and *Viviparus viviparus* (Linnaeus, 1758) in the Wkra River. Both *Bithynia tentaculata* and *Lymnaea peregra* (O. F. Müller, 1774) were eudominants and euconstants in communities in the Łydynia River, whereas *Lymnaea peregra* in the Wkra River. Seven gastropod species were subrecedents as well as accedents of the gastropod communities (Table 4). In the Łydynia River, the values of the Shannon-Wiener index and the Evenness index ranged from 0 to 3.28 and from 0 to 0.98, respectively. At sites 9 and 10, the values of H' and J indices reached 0, because a drastic decrease in the number of gastropods species was observed there. The quantity ratio (the number of specimens of each species) was poorly balanced in the gastropod community at site 5 (dominance was focused on the one species mainly, for example, *Ancylus fluviatilis* O. F. Müller, 1774), thus the value of the Evenness index reached 0.6 (Fig. 2a). In the Pełta River the values of the Shannon-Wiener and the Evenness indices ranged from

TABLE 4. The values of the dominance (D) and constancy (C) indices (%) of the gastropod communities in the rivers.

Species	Łydynia River (n = 30) D	Łydynia River (n = 30) C	Pełta River (n = 24) D	Pełta River (n = 24) C	Sona River (n = 30) D	Sona River (n = 30) C	Wkra River (n = 30) D	Wkra River (n = 30) C
Viviparus contectus (Millet, 1813)	0.4	16.7	-	-	3.4	20.0	-	-
Viparus viviparus (Linnaeus, 1758)	-	-	6.7	4.2	1.2	6.7	25.6	67.9
Bithynia tentaculata (Linnaeus, 1758)	12.1	73.3	8.9	54.2	44.1	66.7	25.4	64.3
Valvata cristata O. F. Müller, 1774	0.8	6.7	0.1	8.3	0.2	3.3	-	-
Valvata pulchella Studer, 1820	0.7	10.0	4.3	25.0	0.2	6.7	-	-
Valvata piscinalis (O. F. Müller, 1774)	22.4	40.0	27.7	29.2	1.0	20.0	4.6	28.6
Valvata naticina Menke,1845	0.2	3.3	-	-	-	-	0.4	3.6
Acroloxus lacustris (Linnaeus, 1758)	4.5	10.0	-	-	0.2	3.3	1.1	10.7
Lymnaea stagnalis (Linnaeus, 1758)	4.9	60.0	3.0	58.3	5.7	63.3	3.7	60.7
Lymnaea palustris (O. F. Müller, 1774)	0.1	6.7	-	-	0.3	3.3	0.3	10.7
Lymnaea corvus (Gmelin, 1791)	1.4	26.7	7.4	20.8	2.2	40.0	0.8	17.9
Lymnaea truncatula (O. F. Müller, 1774)	0.3	10.0	0.1	4.2	0.4	10.0	-	-
Lymnaea auricularia (Linnaeus, 1758)	-	-	0.1	12.5	0.2	3.3	-	-
Lymnaea peregra (O. F. Müller, 1774)	19.2	80.0	17.9	41.7	4.9	60.0	17.0	78.6
Planorbis planorbis (Linnaeus,1758)	1.5	10.0	3.9	33.3	5.2	33.3	2.2	21.4
Planorbis carinatus O. F. Müller, 1774	0.1	3.3	-	-	-	-	-	-
Anisus spirorbis (Linnaeus, 1758)	1.1	16.7	7.0	45.8	0.4	16.7	-	-
Anisus vortex (Linnaeus, 1758)	6.2	33.3	3.0	45.8	8.6	36.7	3.4	50.0
Bathyomphalus contortus (Linnaeus, 1758)	1.3	16.7	0.6	29.2	2.0	10.0	0.3	3.6
Gyraulus albus (O. F. Müller, 1774)	1.7	30.0	0.2	12.5	4.2	36.7	3.3	25.0
Gyraulus crista (Linnaeus, 1758)	-	-	-	-	0.2	3.3	-	-
Hippeutis complanatus (Linnaeus, 1758)	-	-	-	-	-	-	0.1	3.6
Segmentina nitida (O. F. Müller, 1774)	0.1	3.3	-	-	0.2	10.0	0.2	10.7
Planorbarius corneus (Linnaeus, 1758)	1.7	20.0	3.5	50.0	9.6	73.3	4.4	39.3
Ancylus fluviatilis O. F. Müller, 1774	18.2	30.0	0.1	4.2	-	-	2.5	32.1
Physa fontinalis (Linnaeus, 1758)	0.8	16.7	4.2	75.0	5.6	50.0	4.7	57.1
Aplexa hypnorum (Linnaeus, 1758)	0.4	13.3	1.2	29.2	-	-	-	-
Σ of species	23		19		22		18	
Σ of specimens	2,228		2,794		1,977		2,654	

0.0 to 2.80 and from 0.0 to 0.88, respectively (Fig. 2b). From site 5 to site 8, the values of H' indices showed a decreasing and increasing tendency; at site 5 the value of H' index reached 1.98, at site 6 the value of H' reached 2.71, at site 7 and 8 values reached 1.94 and 2.32, respectively. The Evenness index value increased from site 5, where the structure of gastropod dominance started equalizing. In the Sona River the values of H' and J indices ranged from 0.81 (site 1) to 2.93 (site 10), and 0.43 (site 8) to 0.91 (site 4). The maximum value of H' = 2.93 for the gastropods community occurred at site 10 (Fig. 2c). The values of H' and J indices ranged from 1.4 to 2.83 or 0.61 to 0.71, respectively, in the Wkra River (Fig. 2d).

Analysis of the Spearman Rank Correlation Coefficent r_s

The Spearman Rank Correlation Coefficent r_s (n = 38) showed a lack of statistically significant correlations between gastropod density ($r_s = 0.36$, $P = 0.12$), the number of species ($r_s = 0.06$, $P = 0.80$) and the organic matter content in the bottom sediments. There were statistically significant positive correlations between gastropod density and the number of species ($r_s = 0.65$, $P \leq 0.001$) and magnesium concentration ($r_s = 0.44$, $P \leq 0.05$) in the water, the number of species and dissolved oxygen concentration ($r_s = 0.46$, $P \leq 0.05$) (Table 5). The density of gastropods varied from 10 to 135 individuals/m^2 below 11.0 mg Mg/dm^3,

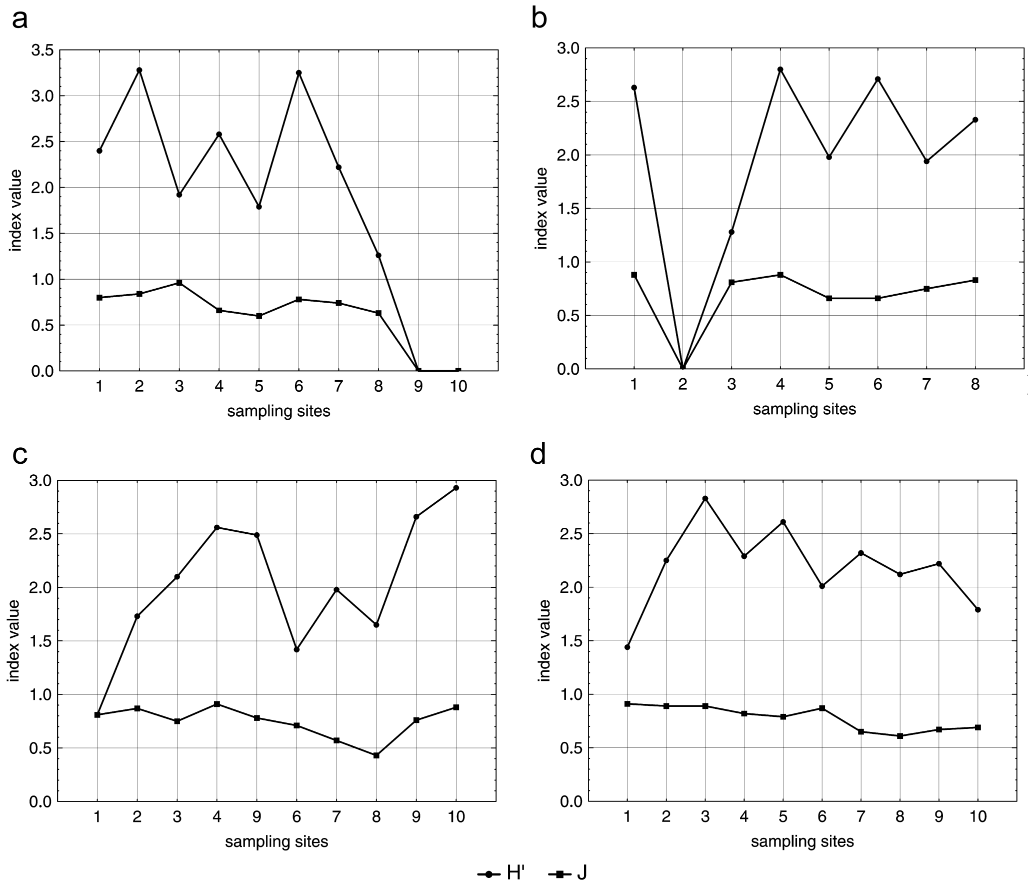

FIG. 2. The value of H’ and J for the gastropod communities in the rivers of the Ciechanowska Upland. (a): The value of H’ and J for the gastropod communities in the Łydynia River; (b): The value of H’ and J for the gastropod communities in the Pełta River; (c): The value of H’ and J for the gastropod communities in the Sona River; (d): The value of H’ and J for the gastropod communities in the Wkra River.

TABLE 5. The values of the Spearman Rank Correlation Coefficent r_s.

Pair of factors	Value of the Spearman Rank Correlation Coefficent r_s
Specimen density and number of species	0.65 $P \leq 0.001$
Specimen density and magnesium concentration	0.44 $P \leq 0.05$
Number of species and dissolved oxygen concentration	0.46 $P \leq 0.05$
Density of *Viviparus viviparus* and pH	0.51 $P \leq 0.02$
Density of *Viviparus viviparus* and BOD_5	0.51 $P \leq 0.02$
Density of *Viviparus viviparus* and chlorophyll *a* concentration	0.56 $P \leq 0.01$
Density of *Lymnaea peregra* and conductivity	-0.54 $P \leq 0.01$
Density of *Lymnaea peregra* and calcium concentration	-0.47 $P \leq 0.05$
Density of *Lymnaea peregra* and sulphates concentration	-0.47 $P \leq 0.05$

TABLE 6. Gastropod distribution depending on the parameters of the water.

Parameter	Range	Density (individuals/m^2)
Density of *Viviparus viviparus* depending on pH, BOD_5 and chlorophyll *a*		
pH	≤ 8.0	0–36
	8.1–8.3	0–70
	≥ 8.4	17–96
BOD_5 (mg O_2/dm^3)	≤ 3.8	0–38
	3.9–5.0	0–70
	≥ 5.1	21–74
Chlorophyll *a* (µg/dm^3)	≤ 10.0	0–36
	10.1–15.0	3–39
	≥ 15.1	1–96
Density of *Lymnaea peregra* depending on conductivity, calcium and sulphates		
Conductivity (µSxcm^{-1})	≤ 500.0	12–90
	501.0–600.0	0–34
	≥ 601.0	0–18
Calcium (mg Ca/dm^3)	≤ 85.0	1–90
	85.1–95.0	3–61
	≥ 95.1	0–18
Sulphates (mg SO_4/dm^3)	≤ 40.0	12–90
	40.1–60.0	1–61
	≥ 60.1	0–13

from 10 to 223 individuals/m^2 at 11.1–17.8 mg Mg/dm^3 and from 36 to 230 individuals/m^2 at above 17.9 mg Mg/dm^3. The number of gastropod species varied from 1 to 9 below 6.6 mg O_2/dm^3 in the water, from 3 to 9 at 6.7–7.1 mg O_2/dm^3 and from 6 to 10 at above 7.2 mg O_2/dm^3. There were statistically significant positive correlations between the density of *Viviparus viviparus* and pH, BOD_5, chlorophyll *a*, and a negative correlation between density of *Lymnaea peregra* and any of conductivity, calcium and sulphate concentration (Tables 5, 6).

Fequency Analysis of Gastropod Communities

The result of the frequency analysis showed statistically significant positive (+), negative (-) or lack of associations (0) between certain gastropod species, for example, *Bithynia tentaculata, Lymnaea stagnalis* (Linnaeus, 1758), *Lymnaea peregra* or *Anisus vortex* (Linnaeus, 1758) and the substratum in the Łydynia River (χ^2_6 = 64.46, P < 0.01), the Pełta River (χ^2_6 = 205.64, P < 0.01), the Sona River (χ^2_6 = 62.03, P < 0.01), and the Wkra River (χ^2_6 = 175.8, P < 0.01). *Bithynia tentaculata* was positively as-

TABLE 7. Gastropod frequency on the substratum in the rivers of the Ciechanowska Upland.

Species	Łydynia River	Pełta River	Sona River	Wkra River
Bithynia tentaculata	sandy-stony (+)	muddy-clay (-)	sandy-stony (0)	sandy-muddy (-) sandy-stony (+)
Lymnaea stagnalis	sandy (-)	muddy-clay (-)	sandy-stony (0)	muddy (+)
Lymnaea peregra	sandy (+)	muddy-stony (-)	sandy-stony (0)	muddy (+)
Anisus vortex	sandy-stony (+) muddy (-)	muddy-stony (-)	sandy-stony (+)	sandy-muddy (+)

sociated with a sandy-stony substratum in the Łydynia River and in the Wkra River an avoiding muddy-clay or sandy-muddy substratum. In the Wkra River, *Lymnaea stagnalis* was positively associated with a muddy substratum. *Lymnaea peregra* was positively associated with a sandy and muddy substratum, whereas *Anisus vortex* was positively associated with a sandy-stony (Łydynia River) and sandy-muddy substratum (Wkra River) (Table 7).

Principal Component Analysis Results

To explore the studied monitoring data set and to examine the similarities of the samples, a chemometrics technique of the Principal Component Analysis was used. As this data set contains measurements performed within different magnitude ranges, the PCA model was constructed for the centered and standardized data. Unfortunately, the reduction of data dimen-

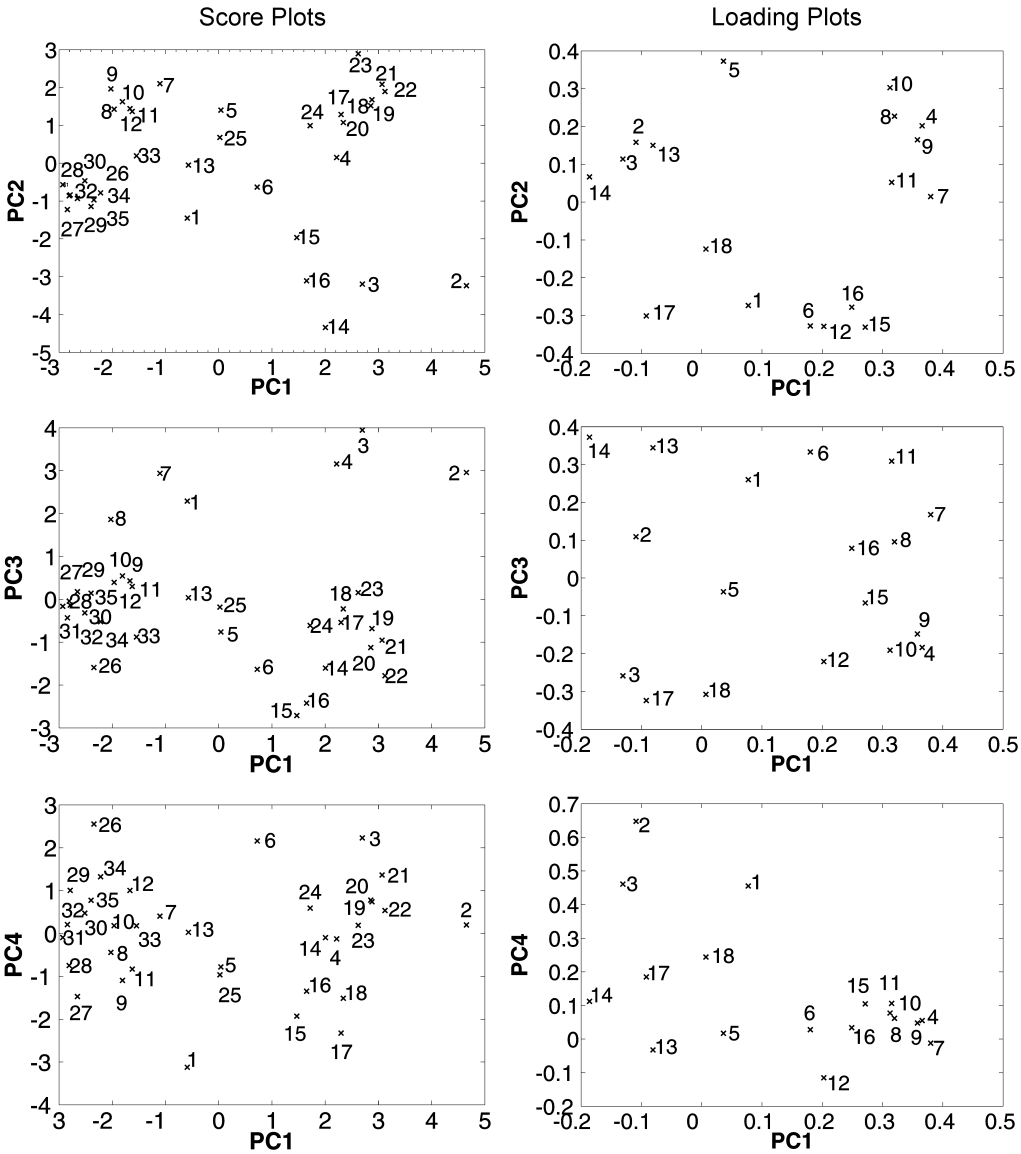

FIG. 3a. Score and loading plots as a result of PCA for centered and standardized data X (35 x 18).

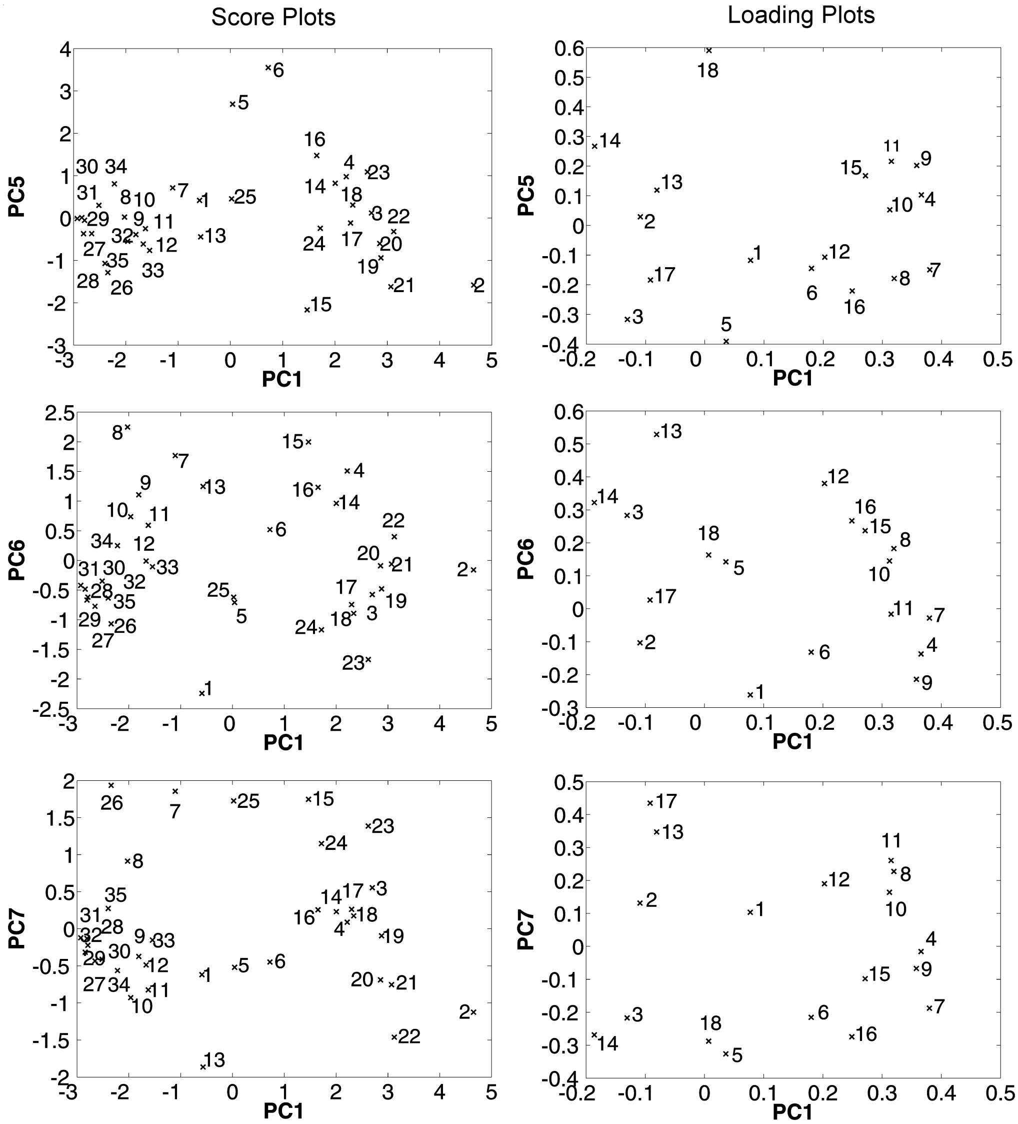

FIG. 3b. Score and loading plots as a result of PCA for centered and standardized data X (35 x 18).

sionality was not too effective, because the PCA model with seven significant Principal Components describes 87.3% of data variance. The score plots and loading plots, which were obtained as a result of this analysis, are presented in Figs. 3a, b.

Based on Figs. 3a, b it is possible to conclude that PC1 reflects the difference between sample sites 8–10 (Sona River), 1–4, 6, 7 (Wkra River), and all remaining samples. Moreover, PC1 reveals the uniqueness of sample site 2 (Pełta River). Based on the loading plot PC1–PC2, it can be stated that sample sites 8–10 (Sona River), 1–4, 6, 7 (Wkra River) differ from the remaining ones, mainly due to the high values of variables 2 (number of species), 3 (pH), 13 (nitrite nitrogen), 17 (chlorophyll *a*) and 14 (nitrate nitrogen). Moreover, PC1 shows the uniqueness of sample site 2 (Pełta River) due to the highest value of parameter 7 (chlorides).

PC2 is constructed mostly due to the difference between sample site 5 (Sona River) and sample sites 2, 3 (Pełta River) 8 and 6 (Łydynia River). Sample site 5 (Sona River) is charac-

terized by a high value of parameter 5 (dissolved oxygen), whereas sample sites 2, 3 (Pełta River) 8 and 6 (Łydynia River) are characterized by the highest value of parameters 6 (BOD_5), 12 (ammonia nitrogen) and 15 (phosphates), as well as the relatively lower values of the remaining parameters.

PC3 shows the difference between sample site 3 (Pełta River) and sample sites 7 and 8 (Łydynia River). Sample site 3 (Pełta River) is characterized by a high value of parameters 1 (gastropod density), 6 (BOD_5), 11 (magnesium), 13 (nitrite nitrogen) and 14 (nitrate nitrogen), whereas sample sites 7 and 8 (Łydynia River) are characterized by the highest value of parameter 17 (chlorophyll *a*).

PC4 reveals the uniqueness of sample site 1 (Pełta River), which is characterized by the lowest value of parameter 2 (number of species), whereas PC5 shows the uniqueness of sample sites 5 and 6 (Pełta River) characterized by the highest value of parameter 18 (density of *Lymnaea peregra*).

Furthermore, PC6 is constructed mainly due to the difference between sample site 8 and sample site 1 (Pełta River), whereas PC7 is constructed due to the difference between sample sites 8 (Sona River) and 5 (Łydynia River). Sample site 8 (Pełta River) is characterized by the highest value of parameter 13 (nitrite nitrogen), whereas sample site 1 (Pełta River) is characterized by the highest value of parameter 1 and 9 (gastropod density and alkalinity). Based on PC7 it is possible to conclude that sample site 8 (Sona River) is characterized by the highest values of parameter 17 (chlorophyll *a*), whereas sample site 5 (Łydynia River) is characterized by the high values of parameters 14 (nitrate nitrogen), 16 (total phosphorus), 18 (density of *Lymnaea peregra*) and 5 (dissolved oxygen).

The PCA loading plots are easy to interpret and reveal a high positive correlation between the parameters, namely:

– cluster 1: parameters 10 and 8 (calcium and sulphates),
– cluster 2: parameters 4 and 9 (conductivity and alkalinity),
– cluster 3: parameters 11 and 7 (magnesium and chlorides),
– cluster 4: parameters 15 and 16 (phosphates and total phosphorus), and
– cluster 5: parameters 6 and 12 (BOD_5 and ammonia nitrogen).

Based on the loading plots it is also possible to observe the negative correlation between parameters 17 and 5 (chlorophyll *a* and dissolved oxygen).

DISCUSSION

Gastropod Communities and their Relation with the Basement Complex and the Substratum

Data of the surveys conducted by Harding et al. (1999) or Dietrich & Anderson (2000) showed that basement complex, substratum, and current velocity influenced the gastropod communities as well as the organic matter content in aquatic ecosystems (Vannote et al., 1980; Delong & Brusven, 1998; Murphy & Giller, 2000).

According to Savage & Pratt (1976), the percentage of organic matter content in the bottom sediments influences the macrophytes richness. In the rivers of the Ciechanowska Upland, the organic matter content in the bottom sediments was low and reached 0.43–28.44%. I did not observe any correlation between gastropod density and either the number of species or the organic matter content of the water. This result is contrary to that of Savage & Gazey (1987), who obtained a statistically significant correlation between *Bithynia tentaculata* occurrence and the content of organic matter. The data from the survey of Dillon (2000), which involved both a substratum and a habitat size, showed an indirect effect of calcium on the gastropod communities. In the New River and its tributaries investigated by Dillon, which passed through a region of gneiss and schist and then through limestone and dolomite, calcium did not affect the abundance of pulmonates directly. The gastropods were rare independent of the calcium content in the water. According to Dillon, the gastropods were also rare in hard water where the tributaries were small. Rosaro & Pietrangelo (1993) claimed that among macroinvertebrates, the gastropods are dominants in streams with a limestone bottom. The result of my survey showed the occurrence mainly of calcite ($CaCO_3$) and dolomite ($CaMg[CO_3]_2$). These minerals could easily dissolve in water. The calcium content in the water varied from 64.90 to 104.70 mg/dm^3. Thus, such concentration of calcium could result in a statistically significant negative correlation between *Lymnaea peregra* density and the calcium content in the water. Collier et al. (1998) came to the conclusion that the gastropod density is negatively correlated with a muddy and a sandy substratum. Strzelec (1993) also showed the negative influence of a muddy substratum on gastropod richness, where only *Lymnaea stagnalis* and *Lymnaea peregra* were present. The results I obtained

confirmed their surveys. In the Łydynia River, gastropod richness was poor on a muddy substratum. Besides, I found statistically significant negative association of *Anisus vortex* with a muddy substratum and *Lymnaea stagnalis* on a sandy substratum. But in the Wkra River, *Lymnaea stagnalis* and *Lymnaea peregra* were positively associated with a muddy substratum. *Bithynia tentaculata* in the rivers of the Ciechanowska Upland were associated with a sandy-stony substratum but avoid a muddy-clay and sandy-muddy substratum. This result confirmed Dussart's (1979) results that *Bithynia tentaculata* occurs on the sediment surface and to a lesser degree is associated with macrophytes. The data of surveys done by Chertoprud & Udalov (1996) showed, that in the rivers 19–20 gastropod species occurred on macrophytes, 12–13 species on a substratum consisting of macrophytes and mud and detritus, and 7–10 species on a stony substratum. By contrast, my survey showed, that particular gastropod species were associated with a particular substratum. Stańczykowska (1960a) and Piechocki (1969) found gastropod diversity and abundance were dependent on the specificity of the study area. In the rivers of the southern part of Poland, for example, *Anisus spirorbis* (Linnaeus, 1768), *Acroloxus lacustris* (Linnaeus, 1758), and species of the genus *Valvata* were totally absent (Strzelec, 1993). These species were detected in the rivers of the Ciechanowska Upland. According to Hubendick (1964, 1972), *Acroloxus lacustris* is typical of reservoirs. By contrast, *Acroloxus lacustris* was subdominant in the Łydynia River, subrecedent in the Sona River and recedent in the community in the Wkra River.

Gastropod Communities and their Relation to Physical and Chemical Parameters of Water

According to Strzelec (1993), the number of gastropod species is negatively correlated with the sulphate and magnesium concentration in water if the sulphate concentration level reached above 210.0 mg SO_4/dm^3. I have found that magnesium concentration is positively correlated with gastropod density in the rivers of the Ciechanowska Upland. Gastropod density was highest when magnesium concentration reached a level of 17.9 mg Mg/dm^3. The density of gastropods also decreased when the magnesium concentration decreased. My result is consistent with the investigation of Shieh et al. (1999). They found the highest gastropod density in rivers when the magnesium concentration ranged from 14.55 to 77.27 mg Mg/dm^3. Dillon (2000) showed that the addition of magnesium to water improved the performance of freshwater snails, provided that the concentration of magnesium did not exceed the concentration of calcium. Magnesium may compete for calcium uptake sites. In the rivers of the Ciechanowska Upland, the concentration of magnesium did not exceed the concentration of calcium.

In the rivers of the Ciechanowska Upland, the sulphate concentration influences *Lymnaea peregra* density. The result of my investigation confirmed the survey done by Clenaghan et al. (1998) that showed a positive statistically significant correlation between gastropod density and magnesium concentration as well as pH. They also found a positive correlation between gastropod density and conductivity, density, and calcium concentration, whereas the results of my survey showed a negative correlation.

Dissolved oxygen seems to play a role in gastropod density (Mouthon, 1996). Boycott (1936) and Hubendick (1972) found that *Ancylus fluviatilis* demanded water with a high level of dissolved oxygen. According to Collier et al. (1998), gastropod density is positively correlated with dissolved oxygen. In the rivers of the Ciechanowska Upland, there was a correlation between gastropod density and the concentration of dissolved oxygen. The number of gastropod species varied from 6 to 10 at above 7.2 mg O_2/dm^3 and from 1 to 10 below 7.2 mg O_2/dm^3. The results of my survey are consistent with the opinions of these authors.

Dillon (2000) found that the diversity of freshwater gastropods was at a maximum in waters of about 5–40 mg Ca/dm^3. Dussart (1976) claimed that the occurrence of *Bithynia tentaculata* is limited to hard- and medium-hard water. The calcium content in the rivers of the Ciechanowska Upland varied from 64.90 to 104.70 mg Ca/dm^3 and influenced *Lymnaea peregra* density only. If the calcium concentration increased up to 95.1 mg Ca/dm^3, the density of *Lymnaea peregra* decreased. If the calcium concentration reached 85.0 mg Ca/dm^3, the density of *Lymnaea peregra* increased. Thus, the results of my survey confirmed the fact that the number of specimens per m^2 reaches higher levels in hard water according to Dussart's classification. Boycott (1936) showed that *Lymnaea peregra* was

most common in water with a calcium concentration from 1 mg to 8 mg Ca/dm^3. Briers (2003) found that variation in the environmental calcium requirement is an important factor in determining the geographical ranges of freshwater gastropods. According to the environmental requirements, *Lymnaea peregra* is classified as a non-calciphilous species (Boycott, 1936; Briers, 2003). According to McMahon (1983), more than 45% of freshwater basommatophoran snails occur only in relatively hard waters, that is, above 25 mg Ca/dm^3. For example, the optimal value of calcium concentration in water for *Lymnaea palustris* (O. F. Müller, 1774) amounts to 30.0–280.0 mg Ca/dm^3, whereas for *Ferrissia rivularis* (Say, 1817) it is 4.6–67.6 mg Ca/dm^3. Growth rate, survivorship, or fecundity rates all decline with a reduction in calcium concentration below optimal values. In the rivers of the Ciechanowska Upland, calcium concentration from 40.0 to 85.0 mg Ca/dm^3 may play a role in gastropod density. Above this concentration, gastropod density decreased. According to Young (1975), if the level of calcium in water is higher than 5.0 mg Ca/dm^3, other factors determine the abundance and density of gastropods. The negative correlation between *Lymnaea peregra* density and a high calcium content in water may explain the statistically significant association of this species with a muddy substratum. A muddy substratum reduces calcium concentration in water by colloid absorption. Calcium does not accumulate in water until a muddy substratum is saturated with calcium (Dussart, 1976). Thus, a muddy substratum "protects" *Lymnaea peregra* against an excessive calcium concentration in water. Shieh et al. (1999) obtained a negative correlation between alkalinity, conductivity and gastropod richness, as well as a positive one between alkalinity and gastropod density. In the rivers of the Ciechanowska Upland, conductivity negatively influences *Lymnaea peregra* density only. If the conductivity increases above 601.0 µS x cm^{-1}, the density of *Lymnaea peregra* decreases. I have found a statistically significant correlation between conductivity and gastropod density, but not between conductivity and the number of gastropod species.

Jokinen (1985) claimed that the number of the pulmonate species is correlated with alkalinity and the catchment area. This result of the survey is easy to understand, because if the level of alkalinity is high, the rate of the allochtonous organic matter exchange is high compared to the lower value of alkalinity in smaller rivers. Thus, rivers with a higher value of alkalinity can feed more invertebrate species. Clarke & Scruton (1997) claimed that in rivers the absence of gastropods is connected with the pH values of water. This conclusion confirmed an investigation by Herrmann et al. (1993), who noticed a rapid decrease in the number of gastropod species if the pH decreased to 5.5. In the rivers of the Ciechanowska Upland, the density of *Viviparus viviparus* decreased if the pH value decreased. The Ciechanowska Upland is a typical agricultural area. The physical and chemical analysis of the water showed high concentration of nitrate nitrogen, total phosphorus, and phosphates. Soil fertilization and discharge of municipal and industrial sewage affect the level of chlorophyll *a* in the rivers of the Ciechanowska Upland. I have obtained a statistically significant correlation between *Viviparus viviparus* density and the chlorophyll *a* level. There is no correlation between the density of *Viviparus viviparus* and either nitrate nitrogen or phosphates. However, the level of chlorophyll *a* in water is dependent on the concentration of these nutrients. Thus, *Viviparus viviparus* may play the role of a bioindicator of eutrophication in running waters.

Gastropod Communities and their Relation to Macrophytes

Some gastropod species are associated with bottom sediments as well as with macrophytes, for example, *Bithynia tentaculata* (Kornijów, 1989). According to Soszka (1975) *Bithynia tentaculata* and *Valvata piscinalis* occur on bottom sediments mainly, and to a lesser degree on macrophytes. *Anisus vortex* is associated mainly with bottom sediments (Kornijów et al., 1990).

In the rivers of the Ciechanowska Upland, gastropods were frequently observed on macrophytes. In the Łydynia River, at one sampling site, *Ancylus fluviatilis* occurred exclusively on *Nuphar lutea* (L.) Sibth. & Sm. *Planorbis carinatus* O. F. Müller, 1774, a species typical of lakes, was present on *Potamogeton crispus* L. Stańczykowska (1960b) and Dvořák & Best (1982) suggested that *Bithynia tentaculata, Lymnaea stagnalis, Lymnaea peregra*, and *Anisus vortex* or *Gyraulus albus* (O. F. Müller, 1774) were not typical phytophilous species. I found that these species occurred on macrophyte surfaces as well as on bottom sediments. This result confirmed

the survey of Kornijów & Gulati (1992). Brown (1997) claimed that gastropods prefer wider the leaf blades of macrophytes rather than narrow leaf blades because they provide more periphyton. According to Brönmark (1989), *Ancylus fluviatilis* occurs on the lateral surfaces of stones because they are richer in diatoms. *Valvata piscinalis* feeds mainly on detritus, whereas green algae and diatoms constitute only a small part of their diet (Kornijów, 1996). McMahon (1983) showed that bottom sediments play a role for freshwater gastropods because minerals comprise a large component of the periphyton on which many gastropods graze. Calcium in the shells derives both from ingested food and bottom sediments. Thomas & Kowalczyk (1997) claimed that the relationship between macrophytes, periphyton, and gastropods is based on mutualism, whereas Jones et al. (2000) obtained the opposite result. According to Dillon (2003), the effects of calcium, alkalinity, conductivity or pH on gastropod communities may be indirect. Thus, higher values of these parameters may influence the production of food on which gastropods might feed. Kołodziejczyk (1984) found that *Bithynia tentaculata* and *Anisus spirorbis* prefer detritus. Thus, it is likely, that the statistically significant association of those species with the bottom sediments in the rivers of the Ciechanowska Upland may be explained by alimentation relationships.

Gastropods, Macrophytes, and their Bioindicative Values

Many authors consider gastropods as a good indicator of sewage, heavy metals or radionuclide concentration in rivers (Dregolskaya, 1993; Abdallah et al., 1999; Flessas et al., 2000). Shieh et al. (1999) claimed that gastropods could be indicators of water hardness. Gastropods are more sensitive to pH changes than fish (Økland, 1983). Calcium is not easily accessible to gastropods at a low pH value (Clarke & Scruton, 1997). Thus, gastropods are good indicators of the acidification of water environments. The results of my survey show that certain physical and chemical parameters influenced the optimal gastropod population development. According to Mouthon (1996), *Valvata piscinalis* and *Viviparus viviparus* showed an association with aquatic environments that are abundant in phosphates and nitrates. In the rivers of the Ciechanowska Upland, the correlation between *Viviparus viviparus* density and the BOD_5 level was statistically significant, so that a moderate load of organic matter appeared to promote its occurrence. *Valvata piscinalis* and *Viviparus viviparus* were numerous in the middle and lower course of rivers, where the concentration of phosphates and total phosphorus was high. In the rivers of the Ciechanowska Upland, gastropods could also be indicators of the concentration of dissolved oxygen. The number of gastropod species increased with an increasing level of dissolved oxygen in water. *Viviparus viviparus* and *Lymnaea peregra* could be indicators of anthropopressure. *Viviparus viviparus* density increased when pH, BOD_5 and the level of nutrients also increased.

According to Thiébaut & Muller (1999), the occurrence of *Elodea canadensis* Michx. in the middle course indicates a progression of eutrophication, whereas *Berula erecta* (Huds.) Coville or *Lemna trisulca* L. indicates oligotrophic water. In the case of my survey, *Elodea canadensis* occurred in the middle course of the rivers, but *Berula erecta* occurred in the upper course of the Pełta River only.

Diversity Indices

According to Trojan (2000), gastropod community diversity depends on the size of the study area, basement complex, and anthropopressure. Clausen & Biggs (1997) showed that the values of the Shannon-Wiener index are high for invertebrate communities and among these for gastropod communities that occurred in smaller rivers compared to communites in larger ones. I have obtained a similar result for the gastropod communities which occur in the Łydynia River and the Sona River, which are tributaries of the Wkra River. Chedwick et al. (1986) found that the Shannon-Wiener index values decreased in rivers under the influence of the metal and mining industries. By contrast, García-Criado et al. (1999) claimed that the Shannon-Wiener index does not reflect the environmental impact of coal mines on community structure in rivers. Perhaps, if they had carried out their survey at genus level instead of the family level, the environmental influences would have been more distinctive. In my survey, the effects on physical and chemical parameters differed from effects caused by the mining industry. The values of H’ and J indices were high for gastropod communities in the headwater of the Łydynia River only. In the lower course of the

Łydynia River, the values decrease to 0. A similar result was obtained by Shieh et al. (1999) in rivers under the influence of industry and agriculture. Strzelec et al. (1999) also claimed that along rivers of the Śląska Upland (southern Poland) gastropod communities decrease. I have not observed a similar tendency in the Sona, Pełta, and Wkra rivers. In the rivers of the Ciechanowska Upland, diversity indices varied from site to site, but did not decrease along the river pollution gradient. The similar tendency was observed by Cao et al. (1996) in the River Trent system: diversity indices varied widely between sites, but did not show a consistent decrease with increasing pollution levels; low values were recorded at both clear and polluted sites.

CONCLUSIONS

Gastropod communities in the rivers of the Ciechanowska Upland are influenced by bottom sediments, the physical and chemical parameters of water, and macrophyte abundance, which are mainly typical of eutrophic water. *Valvata naticina* Menke, 1845, threatened with extinction in Poland, is present in the Łydynia River and in the Wkra River. The result of the survey showed that the range of certain physical and chemical parameters influenced the development of optimal gastropod population and the threshold values at which inhibition of their development occurred. In the rivers of the Ciechanowska Upland, gastropods can be biological indicators of the dissolved oxygen level in water. When the level of dissolved oxygen increased, the number of gastropods species also increased. *Viviparus viviparus* and *Lymnaea peregra* can be indicators of anthropopressure. *Viviparus viviparus* density increased with increases in pH, BOD_5, and the concentration of chlorophyll *a*. *Lymnaea peregra* density decreased if calcium, sulphates, and conductivity increased. The values of diversity indices varied from site to site, but did not decrease along the river pollution gradient, so the result I have obtained is not easy to interpret. Perhaps the diversity indices do not reflect the anthropopressure degree in the rivers of the Ciechanowska Upland. Diversity indices may be more useful for aquatic ecosystems that are more polluted than the rivers of the Ciechanowska Upland. The PCA loading plots mainly showed a high correlation between the physical and chemical parameters.

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